

The Role of Ubiquitous Computing in Facility Life-cycle Information Integration

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ABSTRACT

Mobile computing devices, wireless communications, and sensors have enabled a new era of ubiquitous computing for the facility life cycle of design, construction, operation/maintenance, and disposal/recycle. Compared to other phases, the operation and maintenance phase carries the longest duration and often incurs the highest costs. During this phase, many design and construction problems may surface, causing operational or maintenance problems. These problems can reduce the quality of service and even pose safety hazards to the residents of a facility or the general public. Facility engineers in the past often acted passively; many voiced their dissatisfactions only in undocumented conversations. There is an excellent opportunity to integrate knowledge gained during the facility operation/maintenance phase into other phases of the facility life cycle. Many sophisticated owners are seeing the benefits of a better integration by facility engineers actively participating in design and construction decisions. This integration not only promotes constructability during the design phase, but also facilitates transfer from the construction phase to the operation/maintenance phase. During the operation and maintenance phase, two main challenges exist to all facility operators today —record tracking and resource management. Several advances in information technology are gradually changing the tasks of facility operators and maintainers, especially in mobile computing, wireless communications, and sensors. This paper introduces these new technologies and presents the lessons learned from case studies of research projects conducted at the University of Illinois at Urbana-Champaign.

INTRODUCTION

Facility managers, public and private, face the challenges of managing facilities with limited resources. The performance of these public and private facilities, such as bridges, factories, water treatment plants, warehouses, locks and dams, barracks, classrooms, offices, campuses, hospitals, power plants, ports, harbors, and leased properties, affects the safety and quality of life of millions of people daily. A common response from almost all facility managers is that they are being asked to do more with less and less resources. Many facility managers are using facility management software to track their inventories, maintenance records, conditions, and operating costs. Others are implementing enterprise-to-field level information integration using various hardware devices and software, including the use of the Internet. Several technologies are gradually shaping how facility managers conduct their management tasks. These technological advances are changing the tasks of facility management in the future, a move toward ubiquitous computing. This paper introduces these promising technological advances and presents several case studies from field tests conducted by researchers at the University of Illinois and their collaborators. The paper is organized into four main sections. The first section reviews the needs and tasks of facility operation and maintenance. Next is a description

of existing and emerging hardware and software, which may become indispensable tools for facility managers. The third section describes four case studies of technology field tests. Lastly, lessons learned will be drawn from these cases followed by conclusions.

GAPS IN FACILITY LIFE CYCLE INFORMATION MANAGEMENT

All facilities go through the life cycle of design, construction, operation/maintenance, and recycle/disposal. During this life cycle many individuals and organizations are involved and knowledge generated. Unfortunately, however, there exist many gaps when a facility goes through the life cycle. In a typical design-bid-build project, contractors will only see the design of a facility when it is completed. This lack of input and constructability causes the architecture/engineering/construction industry a great deal of cost overruns, schedule delay, construction claims, and contract disputes. At the completion of the construction phase, many facility managers face the daunting task of establishing accurate as-built information, because many changes usually happen during the construction phase. Significant losses of information and knowledge occur at each exchange of the responsibility between the four phases of the facility life cycle. These losses seem to stem from different viewpoints and responsibilities of parties involved. For example, designers are concerned about functions and forms, while construction managers are focusing on managing construction processes, progress, budget, and safety. Facility managers on the other hand concentrate on facility condition, inventory, and maintainability. Each party involved needs to establish its own information framework to conduct their chartered tasks. Many opportunities for cost saving, constructability, and maintainability are lost because of the lack of integration of information and knowledge during the various phases of the facility life cycle.

PROBLEM STATEMENT

The gaps in information losses during the facility life cycle not only create problems for facility operators and maintainers, but also prevent learning and improvement in design and construction. Can new technological advances help? Which are promising ones? Are there good strategies to implement these new technologies more cost effectively?

RESEARCH APPROACH

To answer the problem statement outlined previously, researchers at the University of Illinois, (1) explored the tasks and challenges of facility management through literature and from the author's personal research, teaching, and consulting experience, (2) identified promising technologies that may play a role to improve the facility life-cycle information integration, (3) conducted field tests of these technological advances, and (4) summarized lessons learned and recommendations from the field tests. The following sections describe each of the tasks.

(1) Review of Facility Management Tasks

From encounters with facility managers, researchers often hear complaints from facility managers on a facility. These complaints in general can be traced to design mistakes or poor construction quality. Many facility managers said they are stuck and have to live with these

mistakes that could be avoided. For example, one frustrated hospital administrator stated that he received approximately 3,000 sheets of design (no as-built update) drawings and one truckload of warranty information on his newly built hospital. It took his staff more than three months, plus \$85,000 of survey contract, to establish accurate facility information so that they can begin to operate effectively. The following highlights the tasks and challenges faced by most facility operators, owners, and administrators:

- Lack of accurate as-built information on drawings and warranty information
- Difficulty in tracing design and construction problems
- Limited record storage space
- Non-computerized data or records-- no search, retrieve, or cross-reference capabilities.
- Errors and inconsistencies in records and facility data
- Tracking of maintenance records and resources (manpower, equipment, and materials)
- Turn-over of personnel and loss of key maintenance knowledge
- Difficulty in prioritizing limited budget for facility maintenance decisions
- Organizational mandates on enterprise integration and decision making
- Labor and resources needed to conduct condition checking or inspections
- More responsibilities with less resources
- Top management needs information within unreasonable timeframe

(2) Identification of Promising Technological Advances

Based on the tasks and challenges identified earlier, an investigation was conducted to identify promising areas in information technology that may improve the tasks of facility operators and maintainers. Three areas were identified to impact the future of facility operation and maintenance: (1) mobile computing, (2) wireless communications, and (3) sensors. These three technologies enable a ubiquitous computing environment, a facility area network, which may well support facility management tasks in the future. The mobile computing devices are becoming cheaper and more rugged with increasing capabilities and speed. Wireless communication network coverage has increased from buildings to campuses to townships, cities, and to metropolitan areas. Sensors are making building components “smart” to automatically report problems or conduct diagnostics. The following sections describe these three technological advances.

Mobile Computing Research and New Advances

Many researchers have contributed to field data collection by developing various hardware and software programs. Among them, Garrett [1998] designed Mobile Inspection Assistant (MIA), a wearable computer, for bridge inspection applications. Liu [1997] developed digital hard-hat systems for construction documentation and collaboration. De La Garza [1998] explored wireless communications and hand-held devices for tracking construction schedule. Pena-Mora [2001] extended collaboration using hand-held computers. Jaselskis [2000] utilized Radio Frequency Identification (RFID) to track and collect data for construction materials. These endeavors have led to new developments as a result of IT advances, especially in the areas of computer hardware, software, and communications. Various industries are exploring new use of these computing devices. Handheld and wearable computers are gaining more popularity in the utility and construction industries. They are used not only to access information in the field but

also to collect data, such as tracking conditions and resources. Many of these handheld computer manufacturers offer attachments such as digital cameras and digital recording of sound, making these handheld computers useful tools for collecting multimedia data. There are three general categories of mobile computing devices available: PDA's, wearable computers, and PC tablets. PDA's are handheld computers, such as Palm or Pocket PC's, capable of collecting field data into databases. They are small and relatively inexpensive, at \$300-\$800 range, running operating systems such as PalmOS and PocketPC. These hand-held computers are considered companion devices that can dock and synchronize with a PC computer to upload or download data. Wearable computers are customized industrialized PC's with a heads-up display which allows hands-free operations. Some include voice recognition and command operations. PC tablets have the size of a laptop computer with a touch-sensitive screen and handwriting capabilities. Weighted at 2-4 lbs, these PC tablets allow field personnel to enter data on electronic forms as if they were writing on a paper form. Another emerging and popular device is the hybrid PDA-phone, which combines cellphone and PDA into one single device. Figure 1 shows some examples of these mobile computing devices.



Figure 1. Wearable and Hand-held Computers

Wireless Communications

Wireless networking has improved dramatically in the last 10 years. The performance of local wireless networks is narrowing the gap with the wired ones. Furthermore, the wide spread of cellular phones, PDA's (personal data assistant), and hand-held computers are creating the need for wide area wireless networking. The increased popularity and usage of wireless data access using hand-held devices have pushed the Internet into cellular phones, PDA's, and hand-held PCs. These wireless Internet access devices are made possible by wireless infrastructure and standards such as CDPD (Cellular Digital Packet Data) in the U.S, GSM in Europe and Asia, and WAP (Wireless Application Protocol) for Web access. Although the bandwidth is still limited, the concept of anytime anywhere e-mail and Web access has gained serious attention from potential users. Many facility operators, such as leasing companies in the Bay area, are

distributing wireless PDAs to their maintenance workers to record conditions and to track costs of maintenance.

Several wireless communication standards are available today. They include IEEE802.11a, IEEE802.11b, IEEE802.11g, Bluetooth, high bandwidth digital cellular network, and satellite communications. IEEE (Institute of Electrical and Electronics Engineers) members and researchers have developed standard protocols for wireless communication networks, which have made it possible for computing devices to communicate with one another. Many mobile and data logging devices are now designed to use these standard protocols so that they can exchange data easily. IEEE802.11a and IEEE802.11b are two of the most widely used standards for wireless communication networks. Bluetooth is another wireless standard that uses different frequencies and bandwidth. Typically used for short ranges of 10 to 100 meters, Bluetooth has the ability to connect sensor clusters and interface with data loggers for field collection of inspection data. The popularity of cellular phones has pushed the demand for high-speed data in addition to voice. Many metropolitan areas now have providers of wireless Internet access from cellular phones and PDAs at 100 to 400 kbps. This will be a technology to watch because many utility companies are considering developing field applications using this infrastructure. For larger area coverage, satellite communications, such as Hughes Satellite Networks, which utilize VSAT low-orbit satellites for telecommunications, allow data to be transmitted from the field to remote locations.

Sensors for Facility & Infrastructure Condition Monitoring

Sensor technologies have dramatically changed the way we collect data from the field. These embedded sensors transmit data related to specific characteristics. Some sensors detect the existence of certain substances; others detect deformations, corrosions, cracks, and loss of cable tensions. Figure 2 shows some of the common sensors used by civil engineers to monitor the health and condition of a facility. They include the accelerometers, strain gauges, tension/pressure meters and tile sensors among others. Although mostly used on research projects at this time, these sensors will eventually become an integrated part of the facility design to collect long-term conditions more efficiently and effectively.

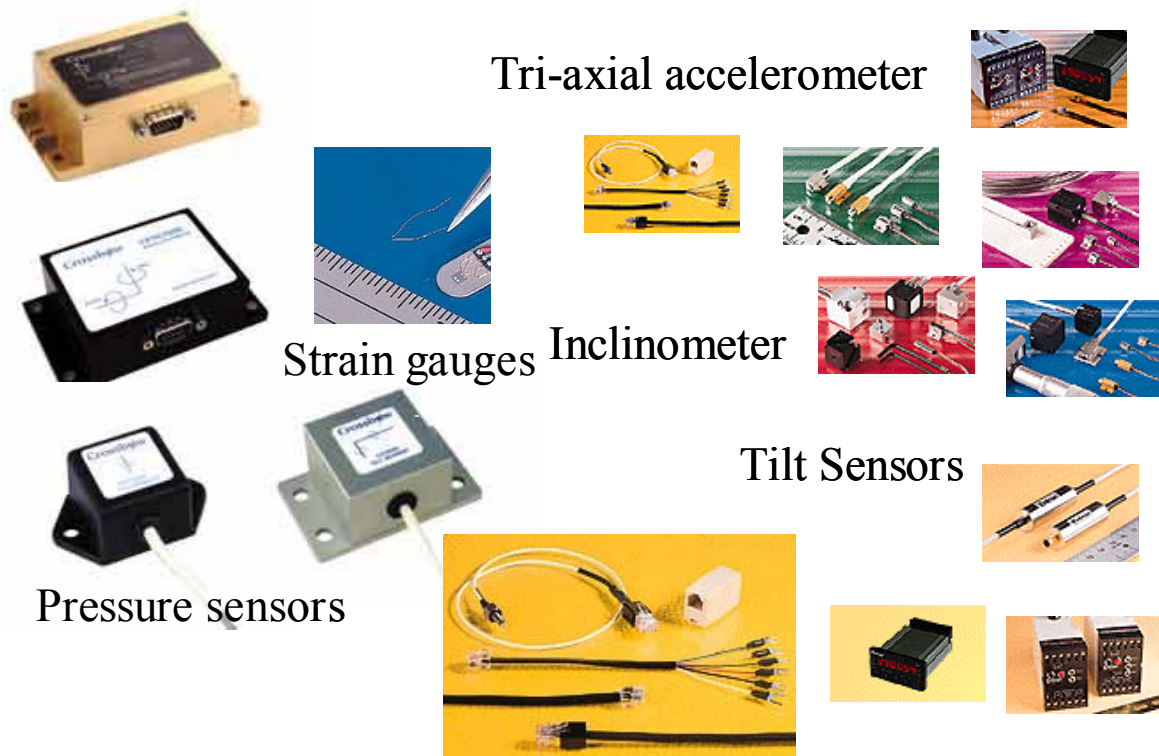


Figure 2. Sensors for Infrastructure Condition Monitoring

(3) Field Test Case Studies and Application Examples

Since 1992, researchers at the University of Illinois have been exploiting promising technologies for use in the facility life cycle. With a mixture of public and private industry funding, several research projects were conducted to field test new information technologies. The following four case studies highlight the scope and the lessons learned from these field tests.

The Digital Hardhat Project System

The Digital Hard Hat system field-tested the pen-based computer, multimedia capture and retrieval, and wireless communications. Various field tests had been conducted to better understand how these technologies may help facility manager (Stumpf 1998). The results indicated both promises and limitations of wireless communications and pen-based mobile computing. This project clearly demonstrated the potential of pen-based computing and wireless communications for facility operators and maintainers.



Figure 3. The Digital Hardhat System

The Tunnel Log System

A second project used to field test mobile computing was the construction of a tunnel in LA. The researchers utilized hand-held PDAs to document a subway construction project near Hollywood station (Liu 2000). Workers in general were receptive to the technologies at the foreman level; however, more training is needed to bring the foremen up-to-date on computer technology. Most foremen seemed to have techno-phobia at first, but after tutorials everyone was able to use the mobile device well, despite the complaints on small screen display and handwriting recognition. In this field test, foremen experimented data entry of daily project information, such as manpower and progress of tunnel grouting.



tunnel-log										
A	B	C	D	E	F	G	H	I	J	K
4	Date	Shift Start		Shift End		Inspector				
5	02/02/99	8:00 AM		6:00 PM		A. Smith				
6	1. WORK INSPECTED AGAINST									
7	Document #	Rev	Approval Status							
8	33-6512A	2	Approved							
9	2. GROUTING LOCATIONS									
10	Briefly summarize hole drilling and grouting activity including grout sequence during shift.									
11	(Show type, location, initial inflow rate and depth of each hole on sketch).									
12										
13										
14										
15										
16										
17										
18										
19										
20										
21	Legend: SP = Sleeve Port, GH = Simple Grout Hole, PH = Probe hole, D = Drilled this Shift									
22	Hydrostatic Head as measured in pump test or packer test									
23	Hole #	Packer	Indicate Whether	Mix	Regular	Pump	# of	# of	Typical	Typical
24		Depths (ft)	Simple Grout/	W/C	Cement	Start	Batches	Sacks	Flow	Pressure
25			SPGP Primary/	Ratio	or	Time		Pumped	Rate	(psi)
26			SPGP Secondary		Microfine				(gal/min)	
27										
28										
29	Daily Report / Daily Report Cont. / SSFG Inspection /									

Figure 4. The Tunnel Log System

BLRA Inspection System

Building and Land Regulatory Administration (BLRA) of District of Columbia conducts construction inspections for all building permits in DC. Administrators, engineers, inspectors, and their staff need to work closely to support construction inspections throughout D.C. A building will typically go through 20-30 inspections during construction and there are over 120 inspectors working in DC on the daily basis. As a IT demonstration project, the researchers at the University of Illinois conducted an end user study, technological analysis, and system prototyping in year 2001-2. The technologies tested included mobile and wearable computers, wireless communication, and web/database connectivity. The prototype BLRA Inspection system allows the integration of field and office data, supporting field inspections with remote 2-way data communications. Using a browser front end and a database backend, the system can accommodate all hardware platforms in use within BLRA, including desktop computers, laptop computers, PC tablets, PDA, and web-enabled cellular phones, which greatly simplifies the implantation challenges and reduces existing investment on computer hardware. Figure 5 shows some sample screens of the BLRA Inspection System.

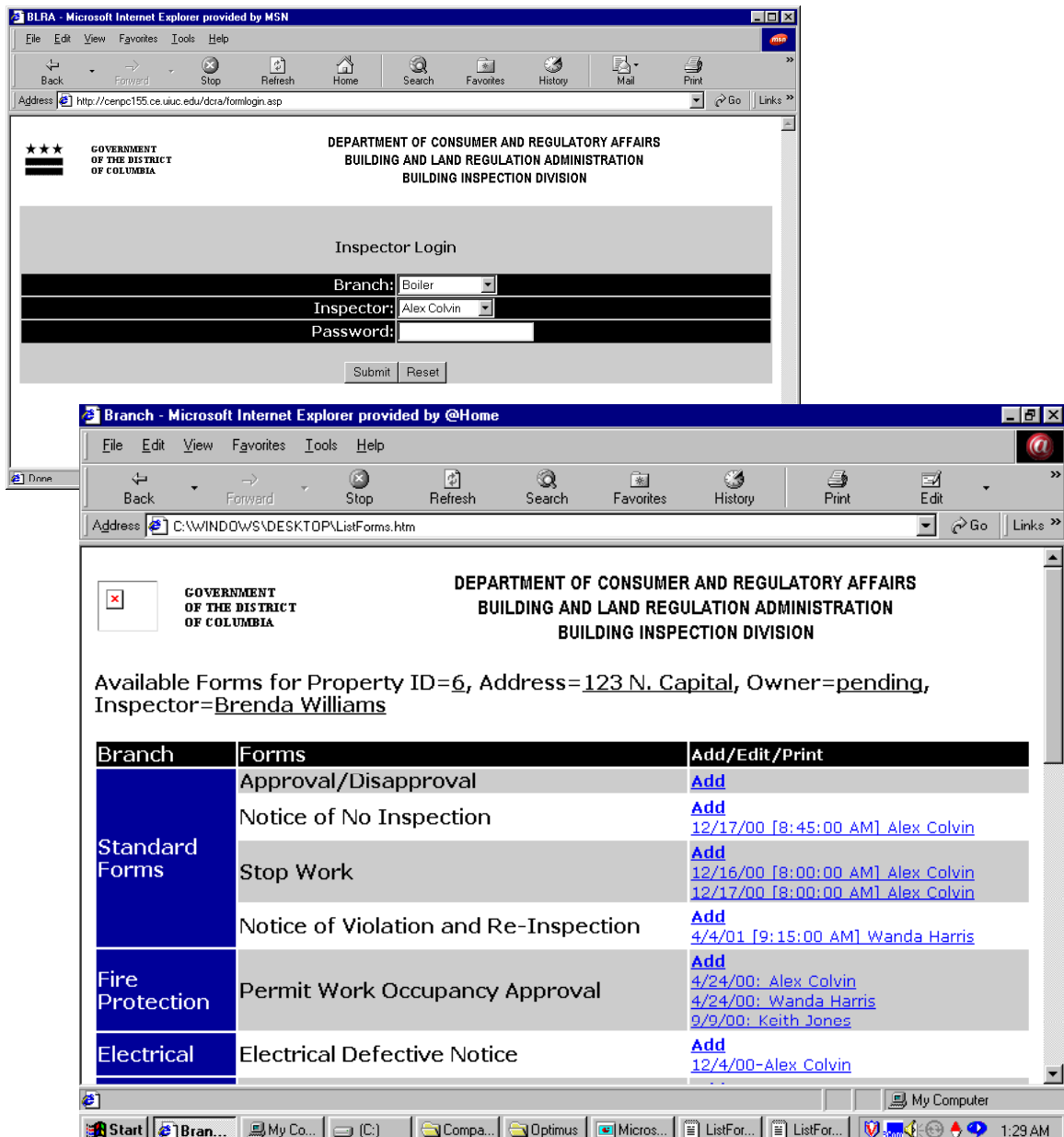


Figure 5. BLRA Inspection System

Sensors for Infrastructure Monitoring

Sensor technologies have dramatically changed the way we collect field data. These embedded sensors transmit data related to specific characteristics. Some sensors detect the existence of certain substances; others detect deformations, corrosions, cracks, and loss of cable tensions. These embedded sensors provide data streams to offsite experts so that inspections can be conducted remotely. Taking advantage of sensor technologies and wireless technologies, researchers at the University of Illinois at Urbana-Champaign field

tested sensors on a model bridge to simulate data communications and management in a sensor-rich environment in the future. Figure 6 shows the model bridge and data obtained on cable strains and bridge accelerations from an induced vibration. Data from remote locations are transmitted via the Internet, so that inspectors can assess the conditions remotely [Ballado, Trupp, and Liu 2003].

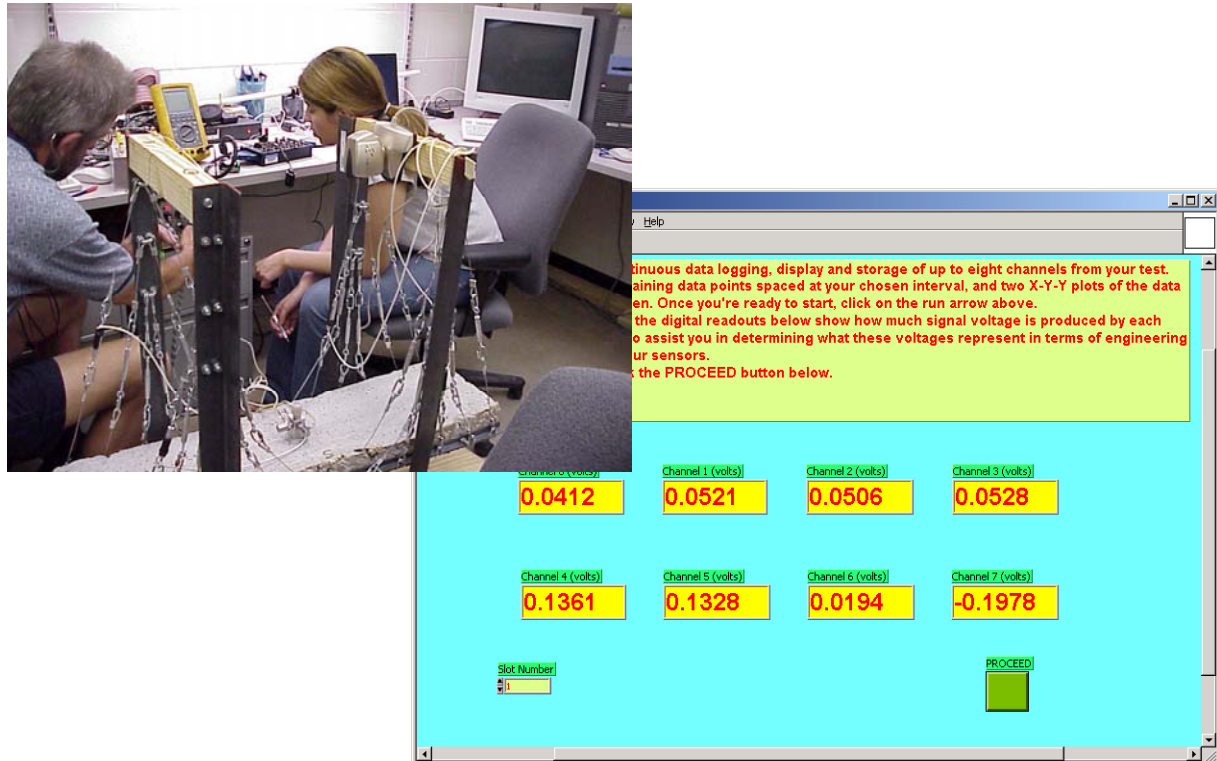


Figure 6. Sensors for Infrastructure Monitoring

LESSONS LEARNED

(1) A Vision for Facility Life Cycle Information Integration

As described in the previous sections, the ubiquitous computing environment will play a key role in facility management in the future. Sensors, wireless communications, and mobile computing will provide a computing environment without boundary to all phases of facility life cycle. This ubiquitous environment will provide better information integration throughout the life cycle. Although there are more issues to be resolved, the technology advances are well positioned to improve how we manage facilities in the future. In addition to the management life cycle of design, construction, operation/maintenance, recycle/disposal, there is likely a life cycle of design of sensor and mobile computing to facilitate the life cycle integration of facility information and knowledge as described in Figure 7.

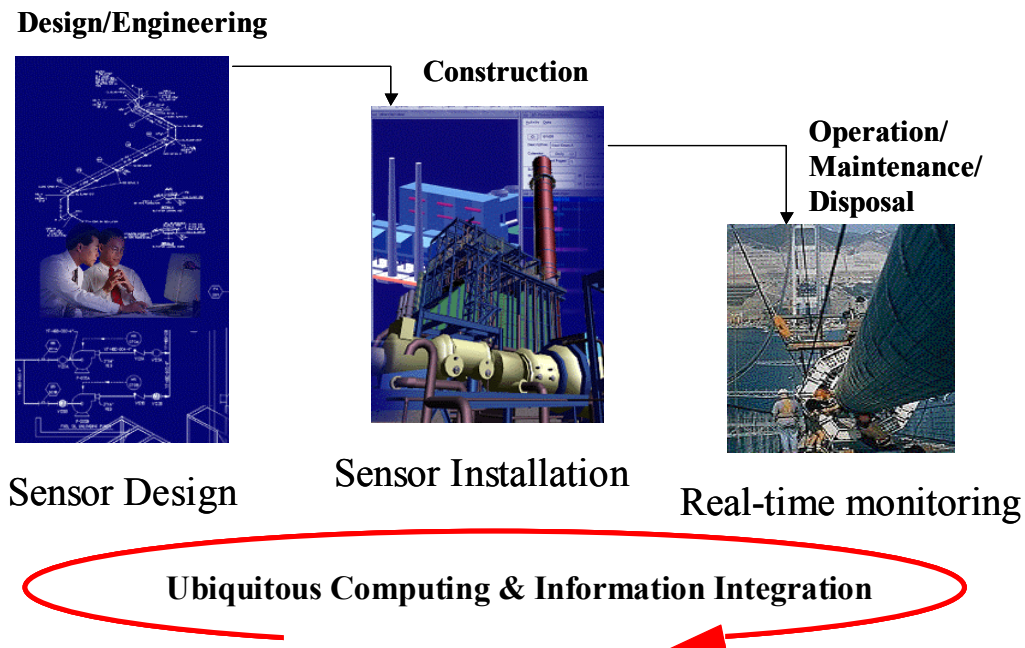


Figure 7. Ubiquitous Computing for Facility Life Cycle Information Integration

(2) Practical Strategies for Implementing New Technologies

As expected, new technologies come with high costs, risks, and implementation problems. Many people asked why they are not seeing a wide spread applications of these technologies. IT managers wonder where the expected payoffs for the investments are. Top management wonders how to choose proper technologies. Workers are puzzled by new systems they have to get used to. These are among the common questions people ask about new technologies. By nature, new technologies are risky. Technologies are developed based on certain assumptions of use and conditions. Many companies take either a positive attitude or a passive attitude toward technologies. The positive ones seek new and innovative ways of doing business, whereas the passive ones catch up because their competitors are using new technologies. Positive or passive, companies or organizations benefit most by understanding the technologies and their work processes. Most successful companies using technologies to their advantages are those that integrate technologies into their processes or invent new processes enabled by new technologies. It is critical for management to realize that technologies are tools, and tools do not produce results if they are not utilized properly. Many new technologies do fail, adding misery to people and organizations that believe in them. Common reasons for these failures include technology assumptions, standards, implementation, and training. Facing all these uncertainties, facility operators and maintainers may consider the following strategies:

- Form an IT committee within the firm to constantly evaluate new IT developments.

- Evaluate new technologies and weigh the benefits/costs, focusing on process reengineering.
- Pilot-test promising technologies on small-scale projects or divisions.
- Compare competing technologies.
- Invest in, not only hardware, but also training.
- Integrate data into information and knowledge throughout the whole life cycle of a facility.

CONCLUSIONS

Information technology tools can and will become indispensable tools for facility operators and maintainers. These tools, especially in mobile computing, wireless communications, and sensors, can help facility managers better track records and manage resources. These technological advances can also improve the integration of information/knowledge, narrowing the information losses and gaps throughout the facility life cycle. Undeniably, new technologies come with uncertainties, risks, costs, problems, and resistance. Facility managers interested in implementing these technologies must recognize the nature of new technologies, their lifecycle, and most importantly how to integrate their work process with technologies. Adopting technologies for technology's sake often leads to failures. A winning strategy for adopting new technologies hinges upon a common vision among management, users, and industry standards. It is important for facility managers to articulate their needs to the hardware and software industry so that more products will be developed toward the needs of facility operation/maintenance-- the longest duration of facility life cycle. Sensors, mobile devices, and communication tools will continue to shape and change how we manage a facility throughout the life cycle. Good returns on technology investment can only be ensured if a prudent implementation strategy is developed and implemented. Among various responsibilities of facility operators and maintainers, the record tracking and resource management are the most challenging ones. These two tasks can be very well served by using sensors, mobile computing, and wireless technologies. In the current climate of tight budget and lean resources, using technologies might be the only means to achieve more with less.

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